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When will Summer Arctic Sea Ice Disappear?

Maslowski, Wieslaw

þÿ Sustainability Weeks 2008 Symposium on Drastic Change in the Earth S
Warming, Sapporo, Japan, 24 June 2008
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When will Summer Arctic Sea Ice Disappear?

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Sustainability Weeks 2008 – Symposium on Drastic Change in the Earth System during Global Warming
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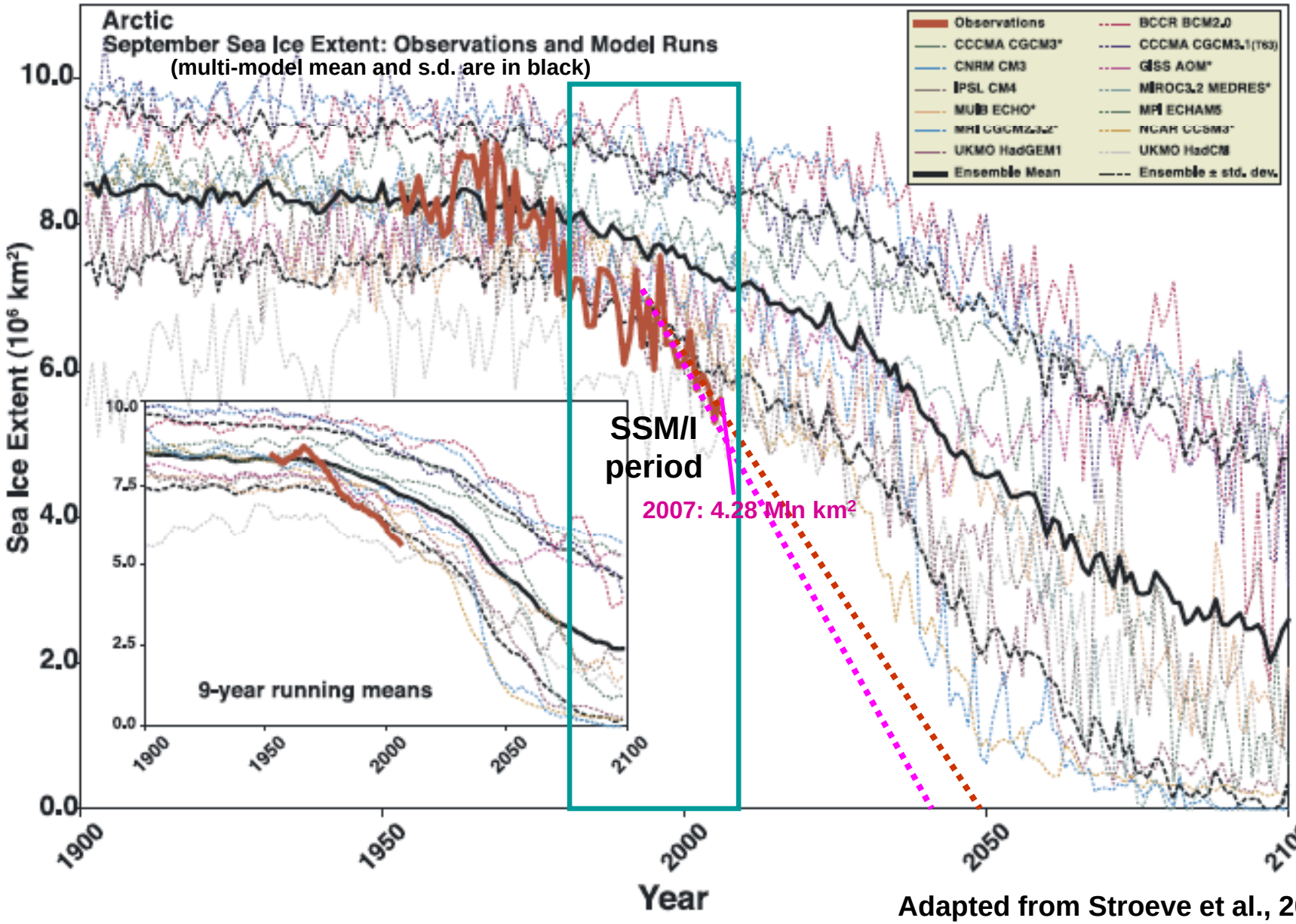
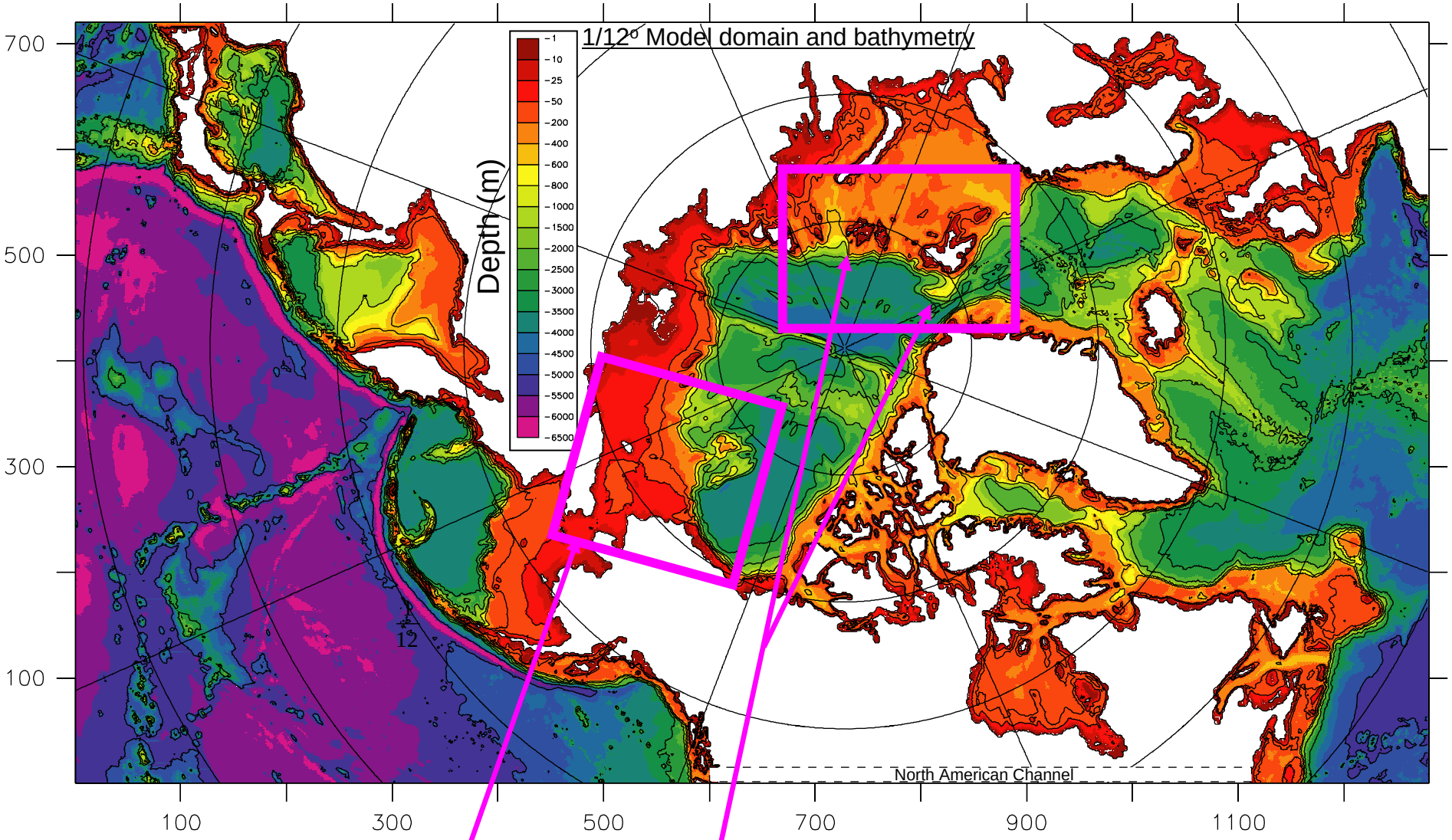
Observed rate of loss of Arctic ice extent is faster than IPCC AR4 predictions



Adapted from Stroeve et al., 2007

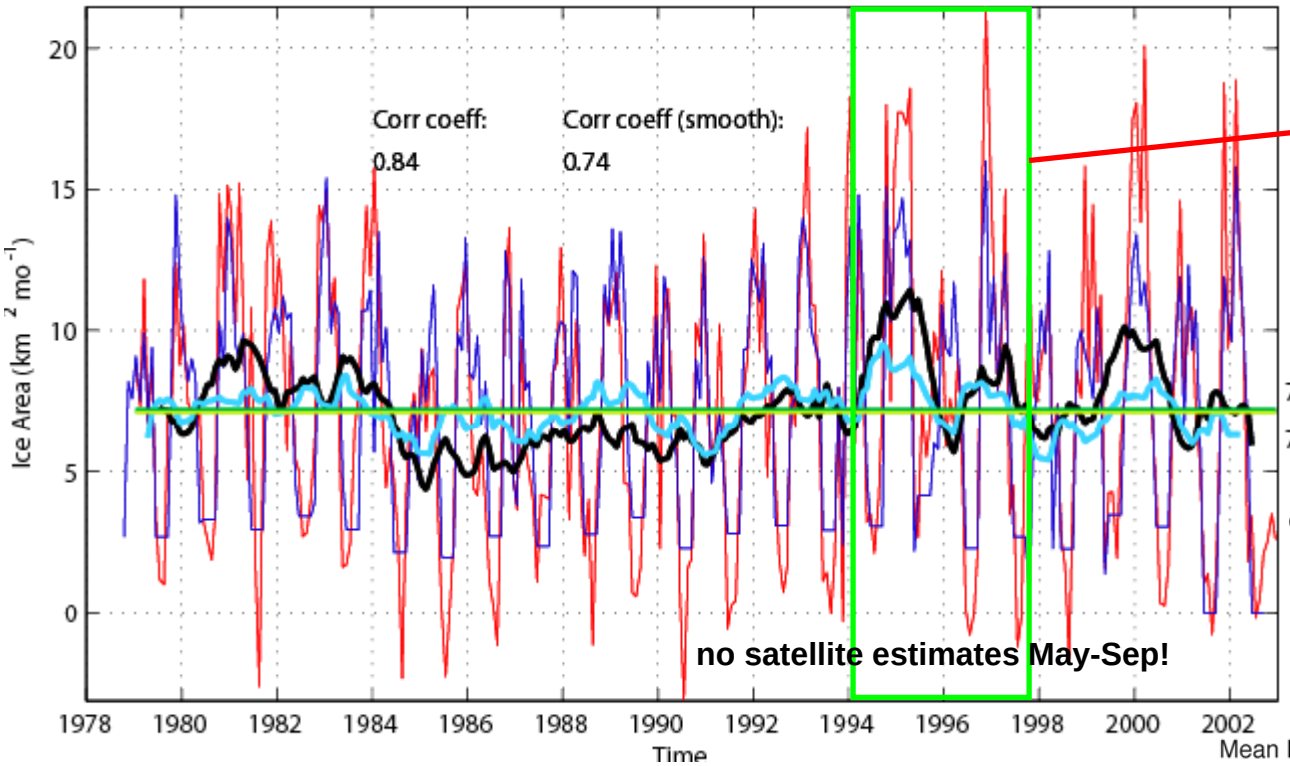


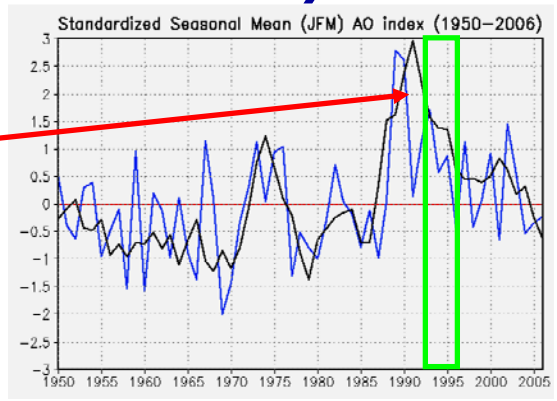
Gateways/Margins of Pacific Water and Atlantic Water Inflow into the Arctic Ocean

Main uncertainties of importance to global climate

1. Northward heat transport from the N. Atlantic/Pacific to Arctic Ocean *
2. Arctic sea ice thickness and volume *
3. Freshwater export from the Arctic to North Atlantic

Sea Ice Export through Fram Strait (wind-driven)





71876

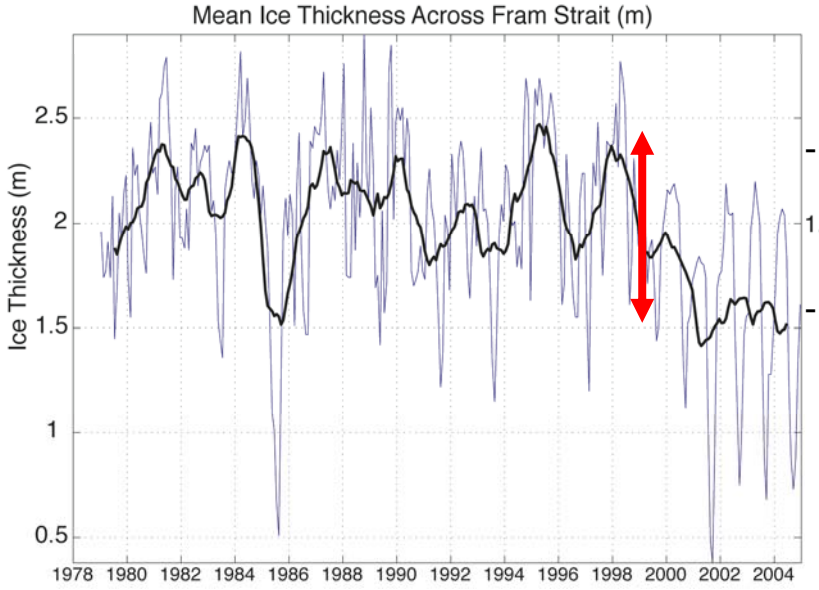
71198

<1% difference

Mean area flux [km²/mo]
Estimates from:
- satellite (Kwok et al., 2004 blue/cyan/yellow)
- model (red/black/green)

High export of thick sea ice from the Artic Ocean in the mid-1990s:

- in response to high positive AO/NAO
- mean thickness of sea ice across Fram Strait decreased by ~70 cm (or ~1/3)
- less multi-year ice in the Arctic Ocean
- warming more pronounced on thinner ice
- thinner ice less stable to perturbations

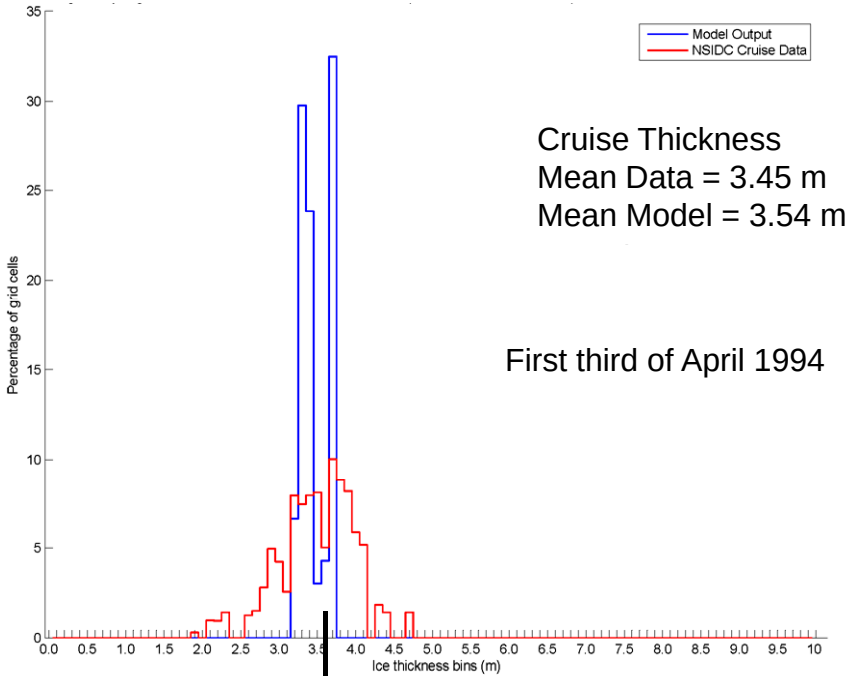


- 2.2

1.98

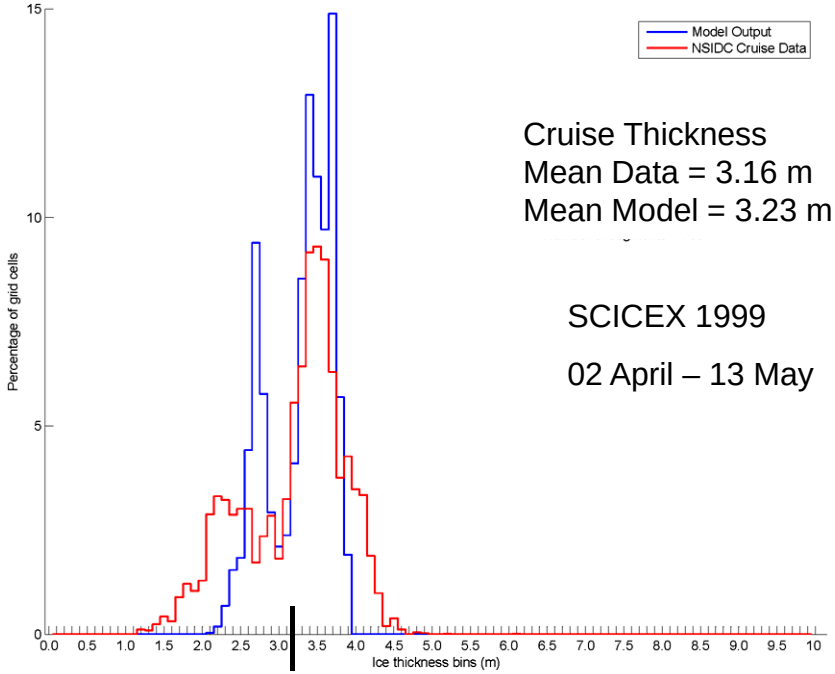
- 1.5

PDFs of ice thickness from submarines (top) / ICESat (bottom) and NPS model (blue)



Cruise Thickness
Mean Data = 3.45 m
Mean Model = 3.54 m

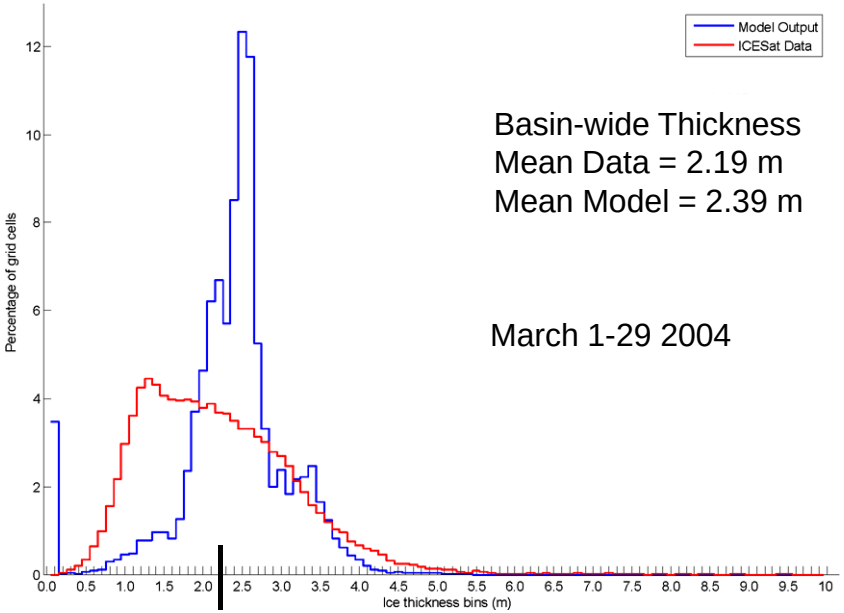
First third of April 1994



Cruise Thickness
Mean Data = 3.16 m
Mean Model = 3.23 m

SCICEX 1999

02 April – 13 May

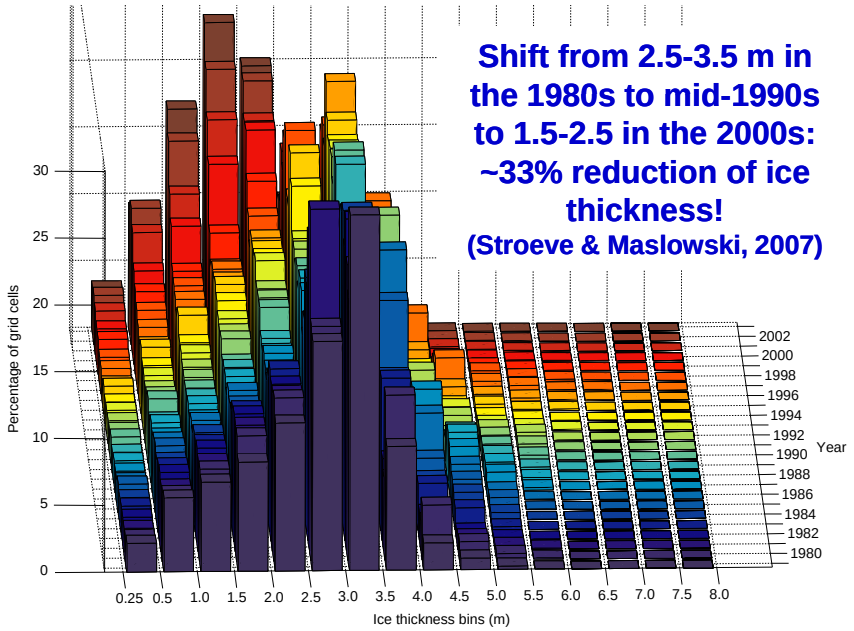


Basin-wide Thickness
Mean Data = 2.19 m
Mean Model = 2.39 m

March 1-29 2004

(from McNamara, 2006 and Whelan, 2007)

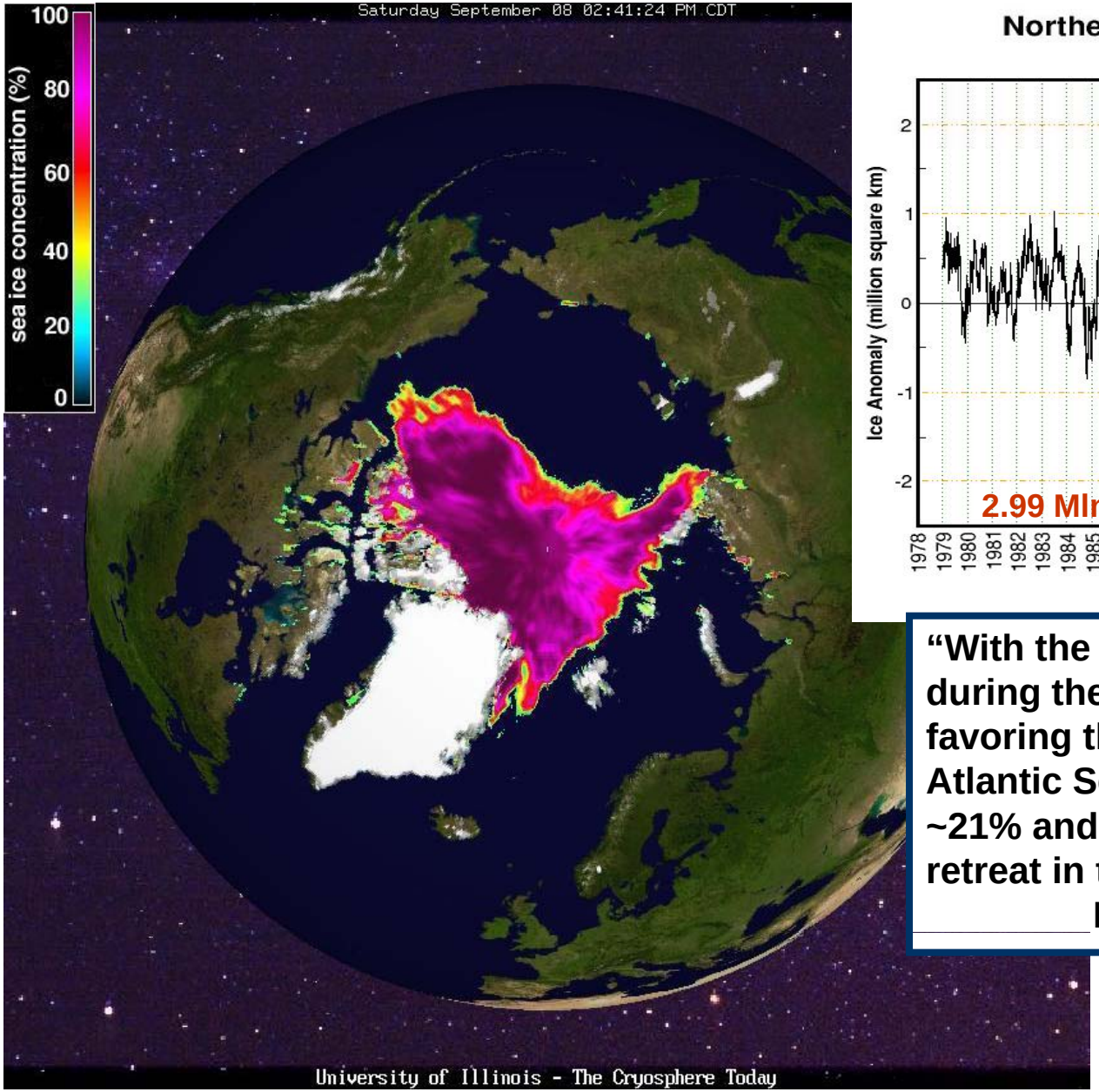
PDF of Model 1979-2003 Annual Sea Ice Thickness

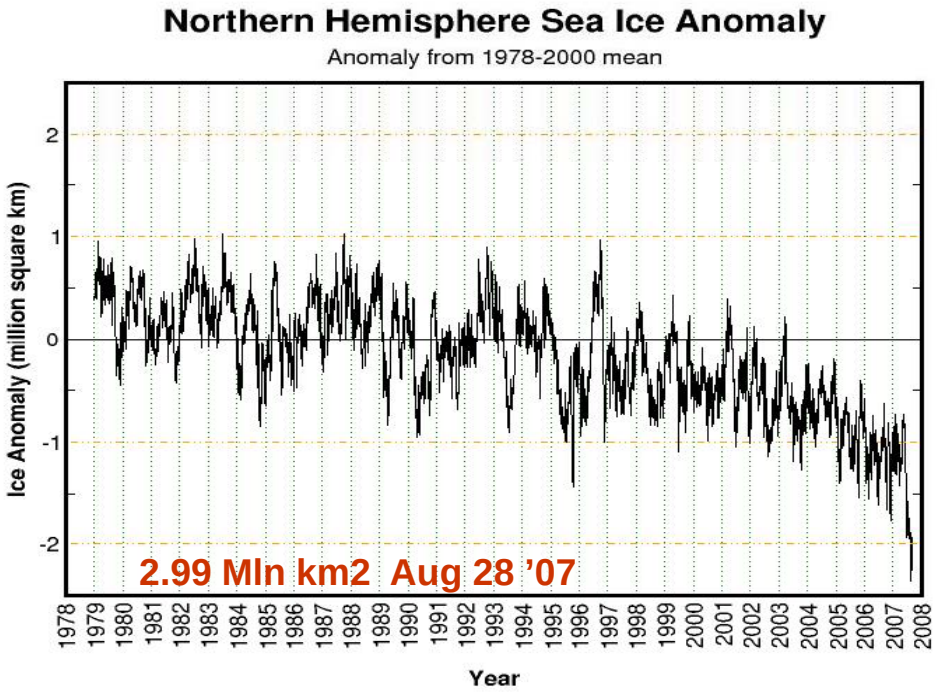


Shift from 2.5-3.5 m in the 1980s to mid-1990s to 1.5-2.5 in the 2000s: ~33% reduction of ice thickness!

(Stroeve & Maslowski, 2007)

Atmospheric forcing of the 2007 summer ice minimum?



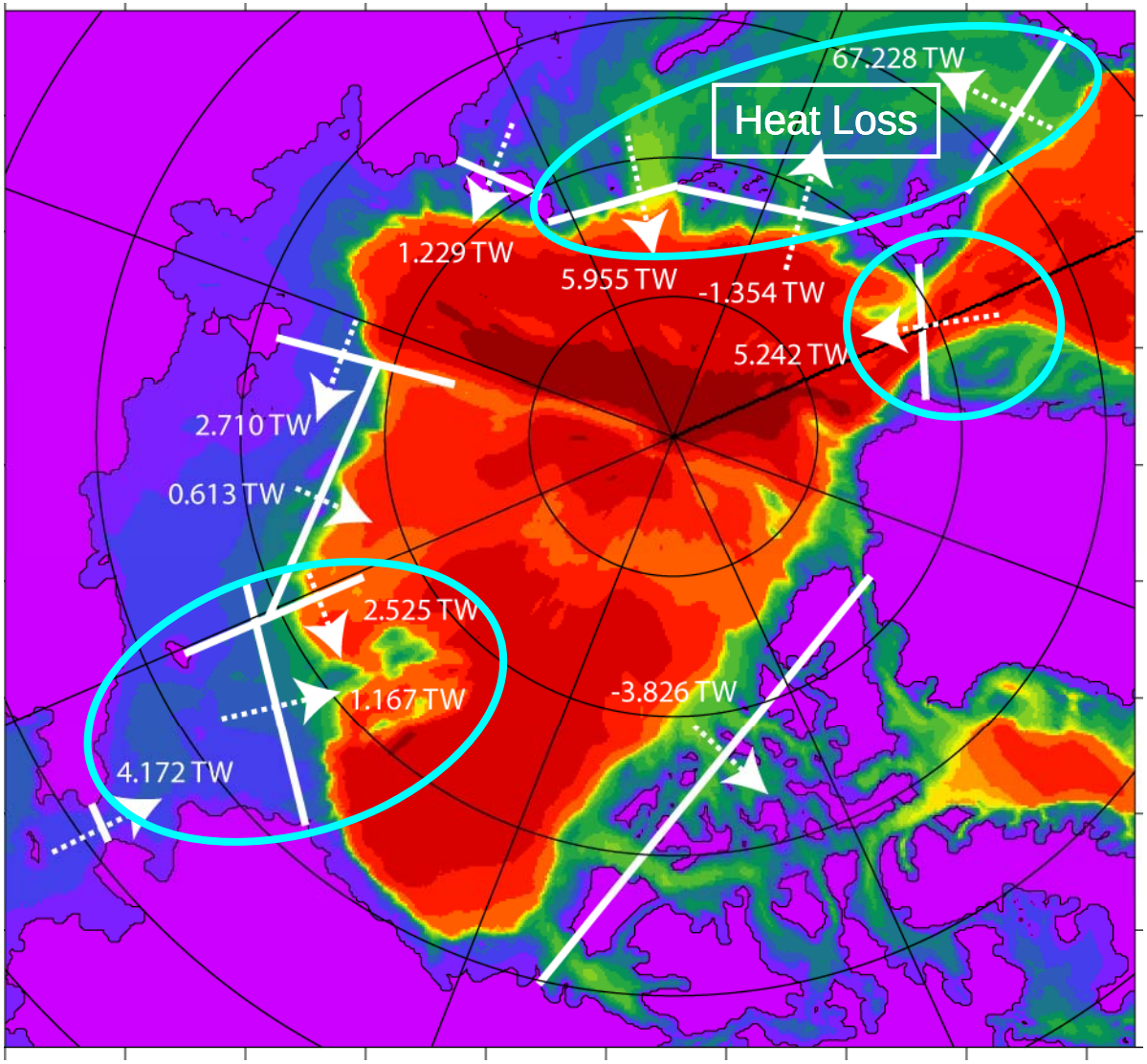


"With the sea-level pressure patterns during the summer of 2006 and 2007 favoring the export of sea ice into the Atlantic Sector, the regional outflow is ~21% and ~15% of the total sea ice retreat in the Pacific sector. "

Kwok GRL 2008

Why no record minimum in 2006?

1979-2004 Mean Oceanic Heat Convergence: 0-120 m; $T_{ref} = T_{freezing}$



Modeling Challenges: Inflow of Pacific / Atlantic Water into the Arctic Ocean and impacts on the sea ice

- Pacific Water entering via narrow (~60mi) Bering Strait and across Chukchi shelf

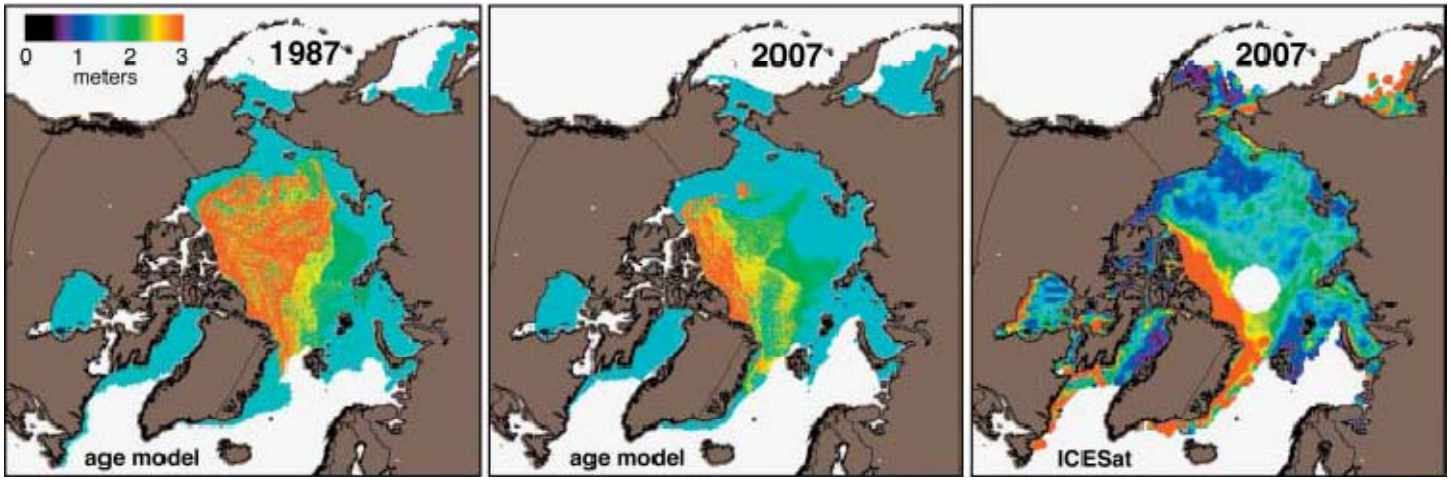
  (Clement et al., DSR II 2005)
- outflow through Fram Strait vs. Atlantic Water inflow (FSBW/BSBW)

  (Maslowski et al., JGR 2004; Stroeve and Maslowski, 2007)
- Atlantic (BSBW) and Pacific Water each losses majority of heat to the atmosphere before entering Arctic Basin

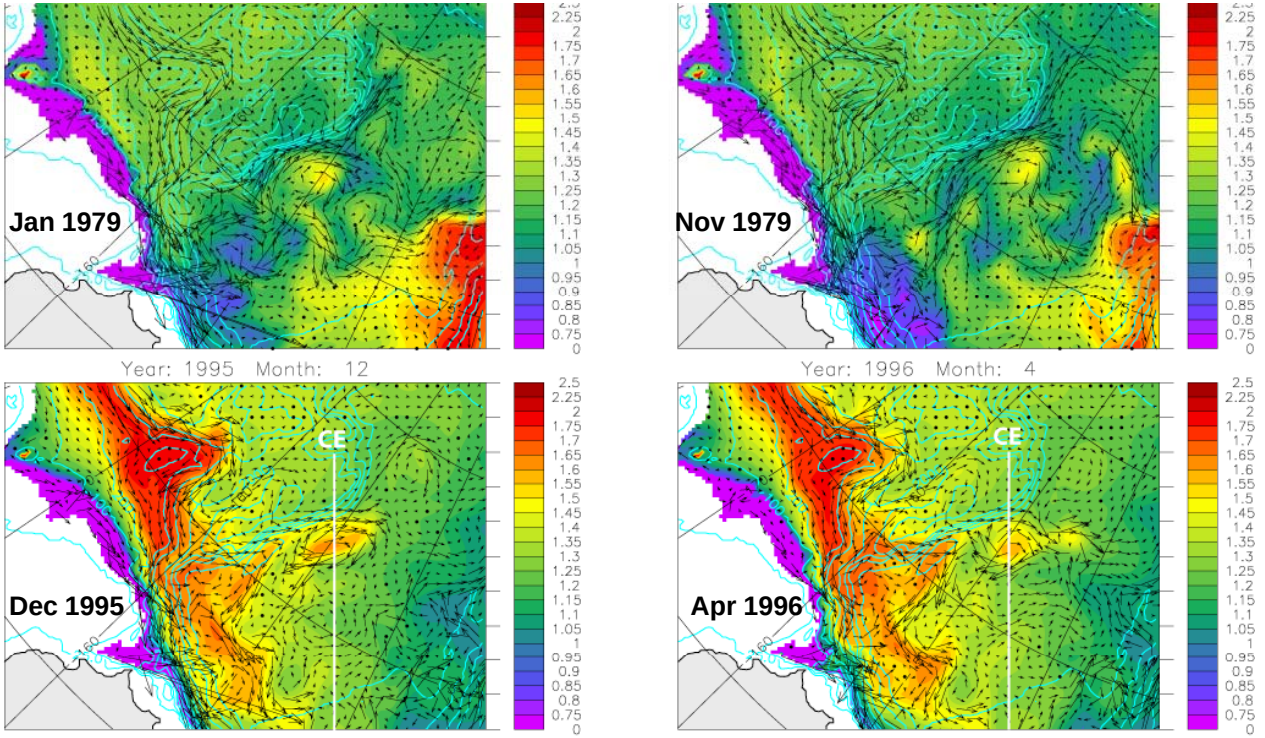
<u>High resolution is one of the top requirements for advanced modeling of Arctic climate</u>

(Maslowski et al., 2008)

Ice Thickness estimates based on age (a) 1987, (b) 2007, and ICESat freeboard (c) 2007



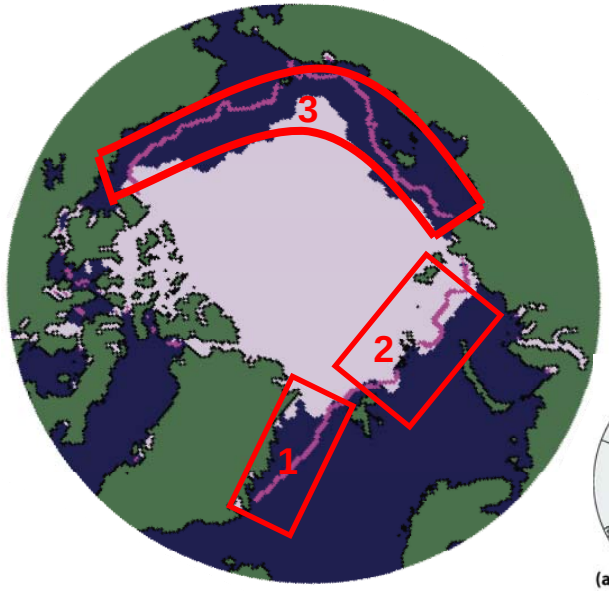
Depth-averaged (65-120m) temperature above freezing and velocity



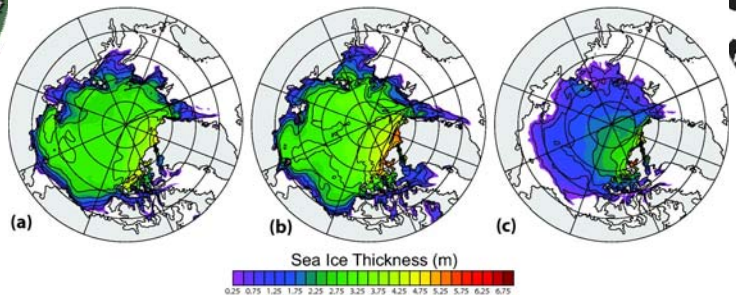
Increasing impact of eddy-driven oceanic heat advection in the western Arctic

GCM Comparison: September 2002

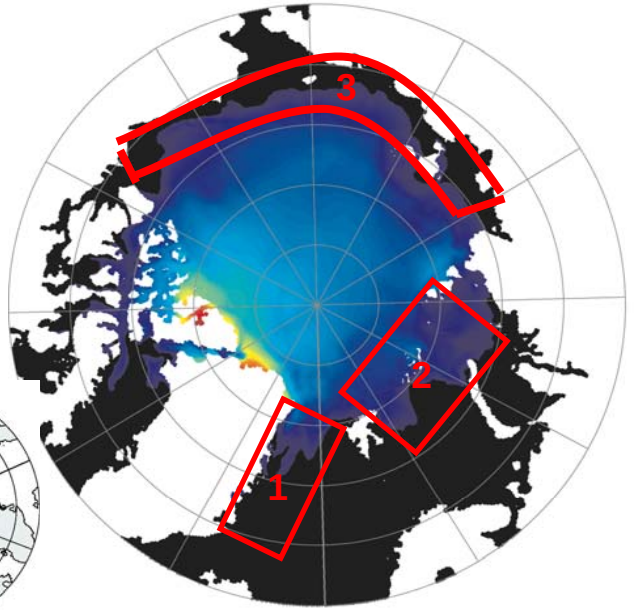
NSIDC ice extent



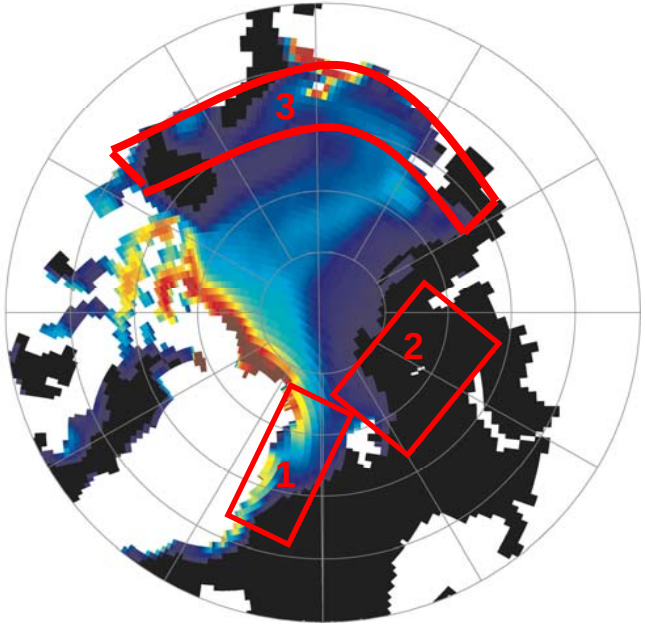
NAME sea ice thickness (m) in (a) 1982, (b) 1992, (c) 2002
(Maslowski et al., 2007)

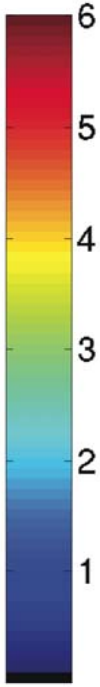


NAME Ice Thickness (m)

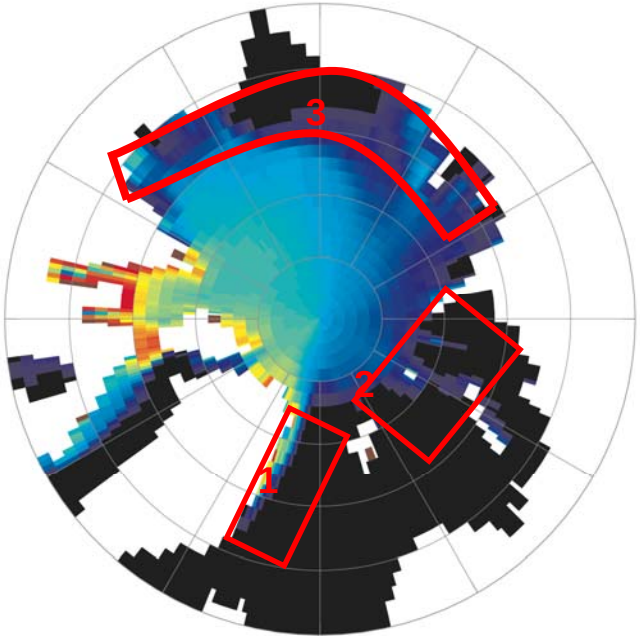


CCSM3 Ice Thickness (m) - ES01(b)

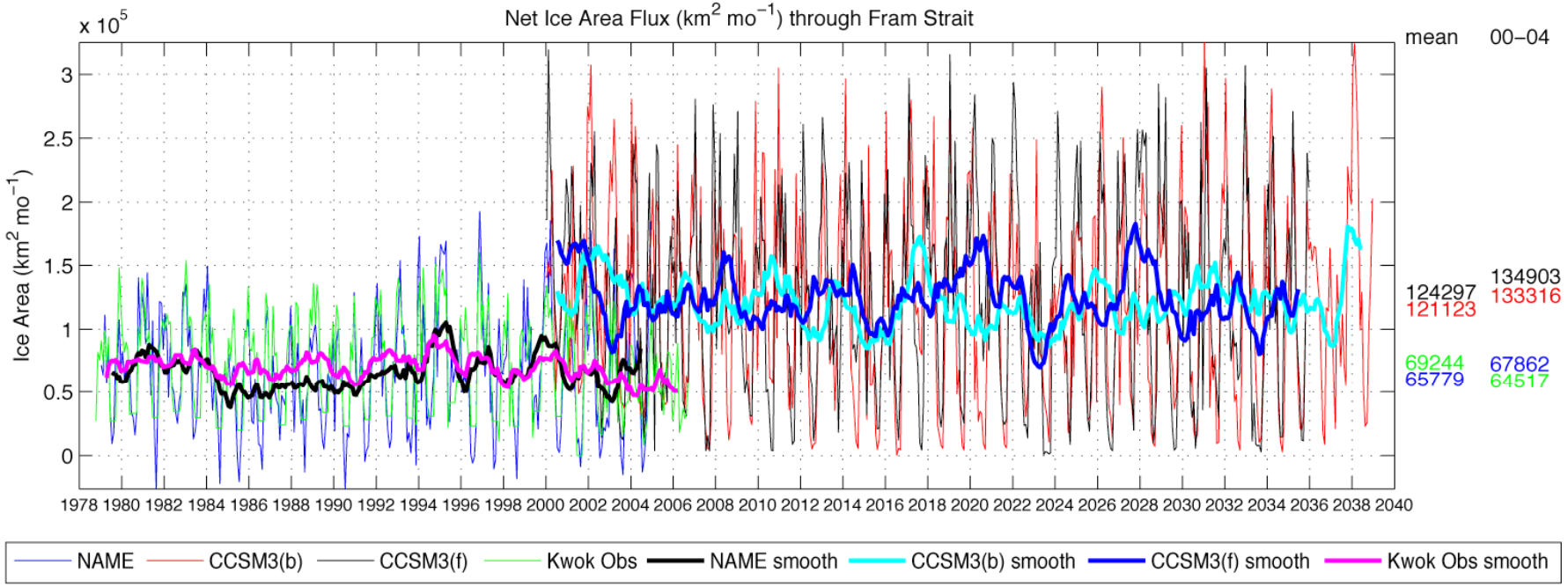


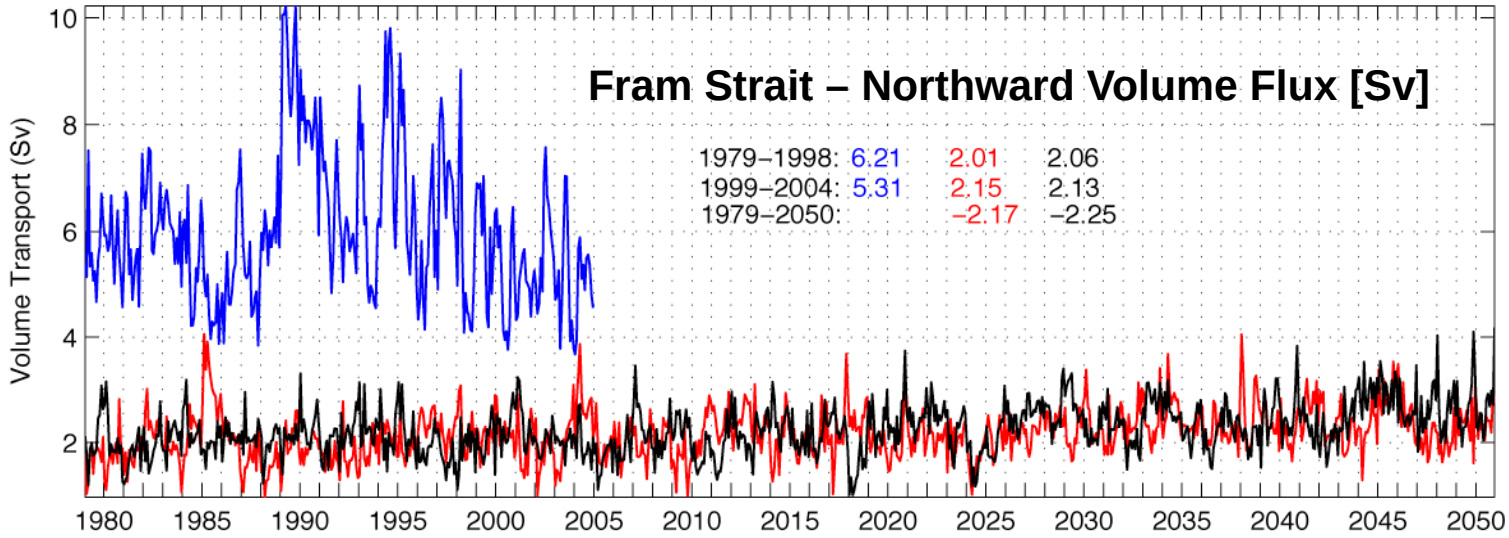


HadGEM1 Ice Thickness (m) - sresa1b(run1) - Sep 2002

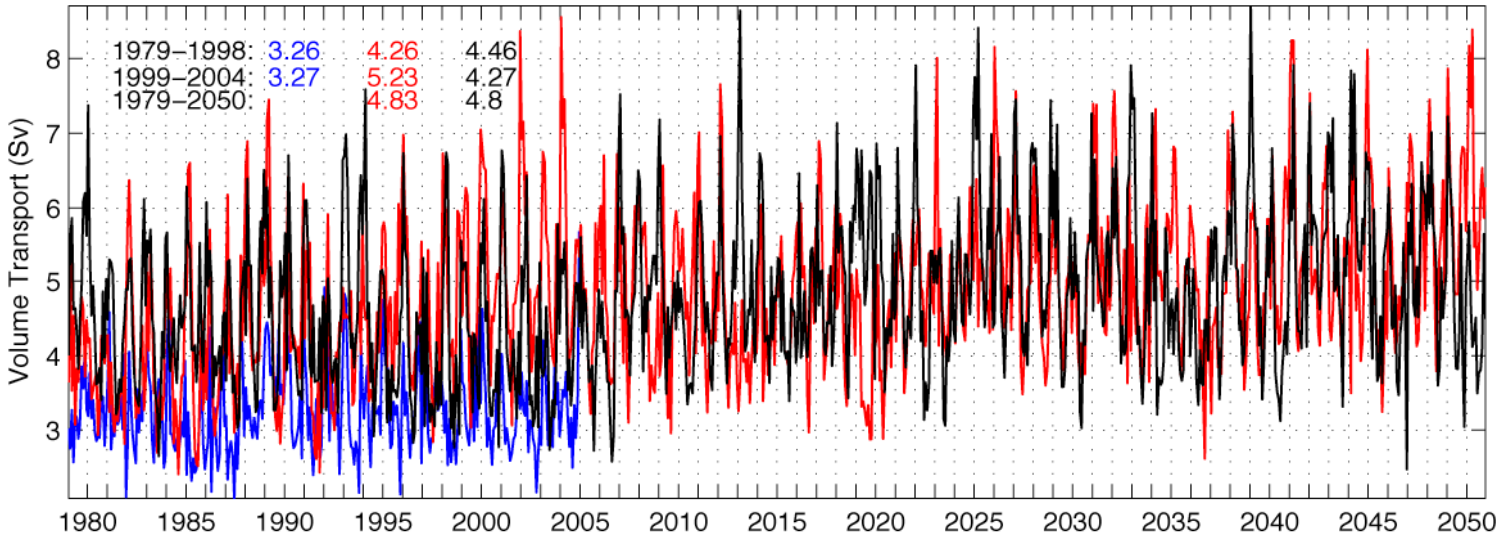


Comparison of areal sea ice export via Fram Strait

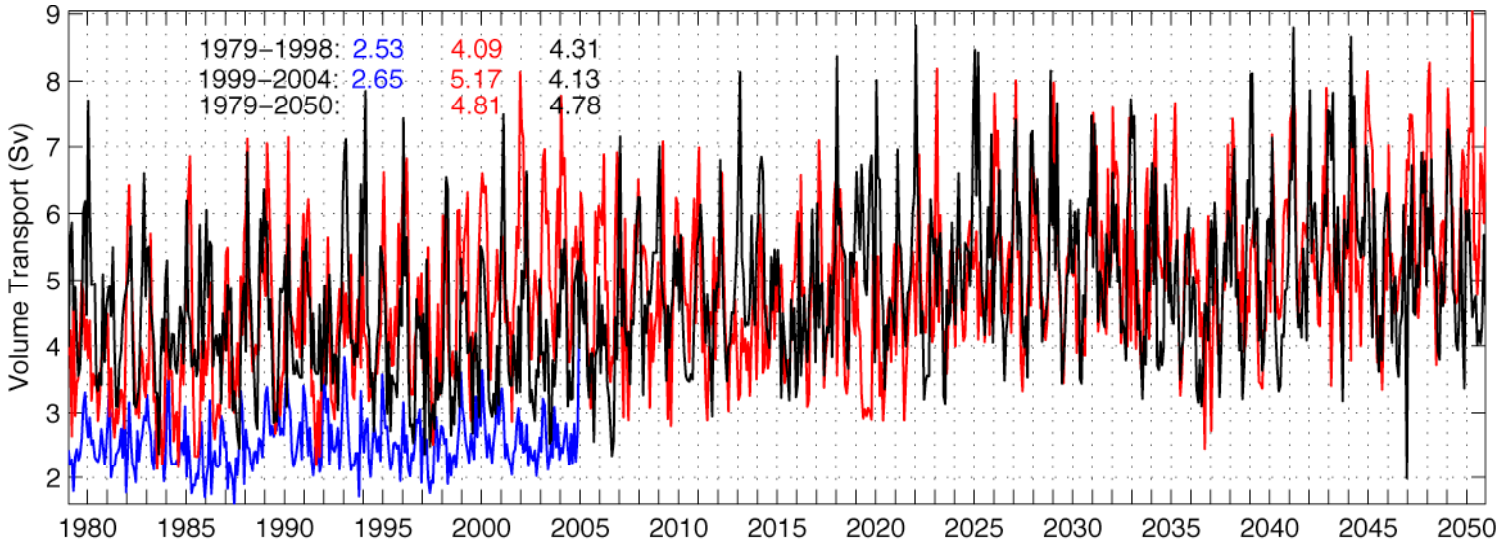




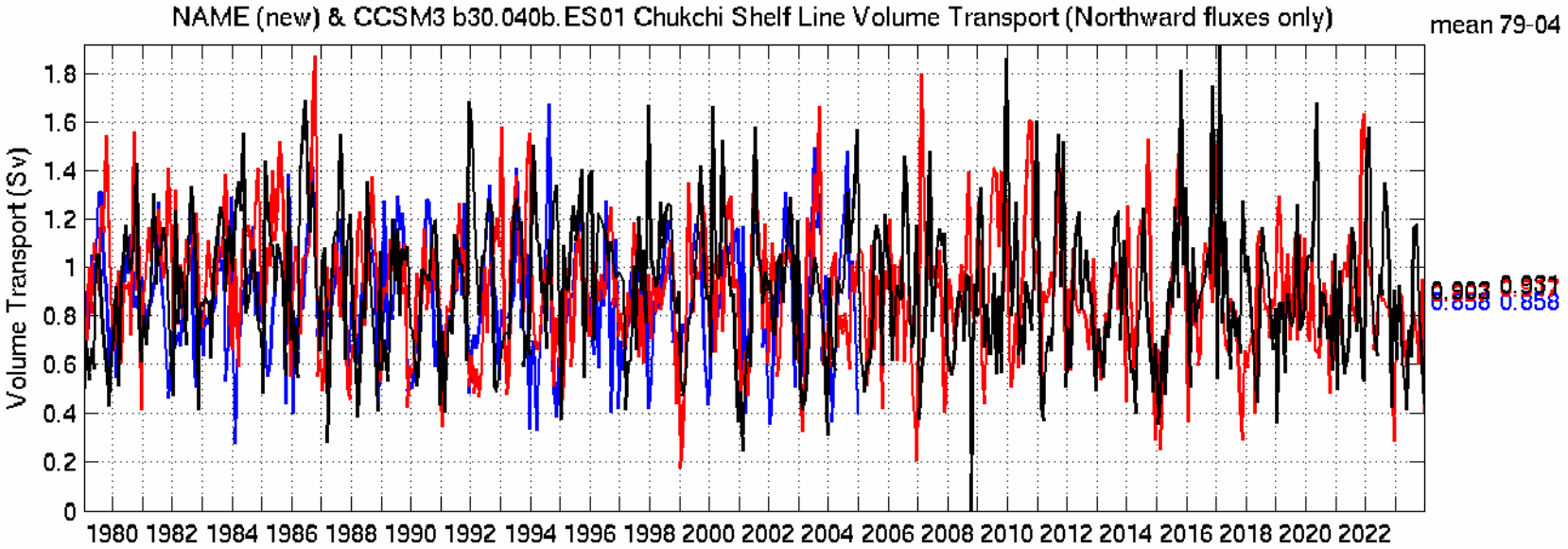
BSO – Net Volume Flux [Sv] – positive east

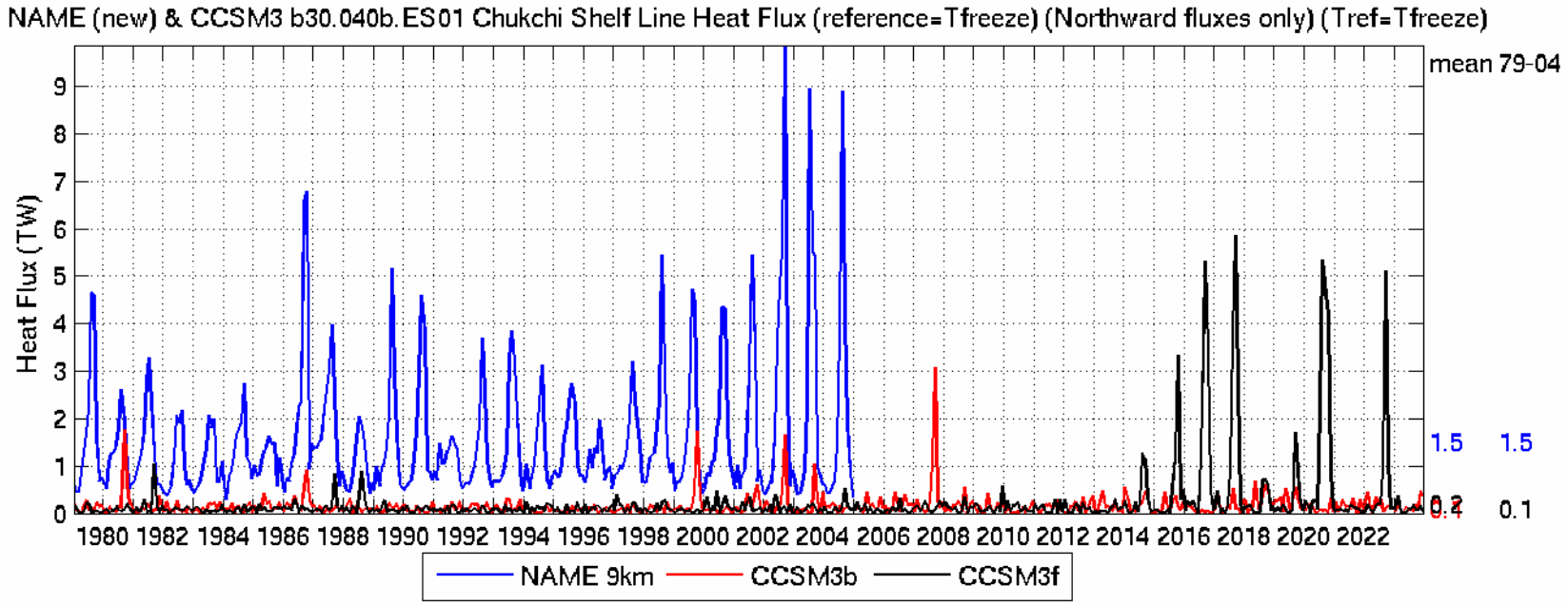


FJL-NZ – Net Volume Flux [Sv] – positive east



Volume and Heat Fluxes from the Chukchi Shelf into the Western Arctic





25-year mean volume transport (Sv) / heat trasnsport (TW)

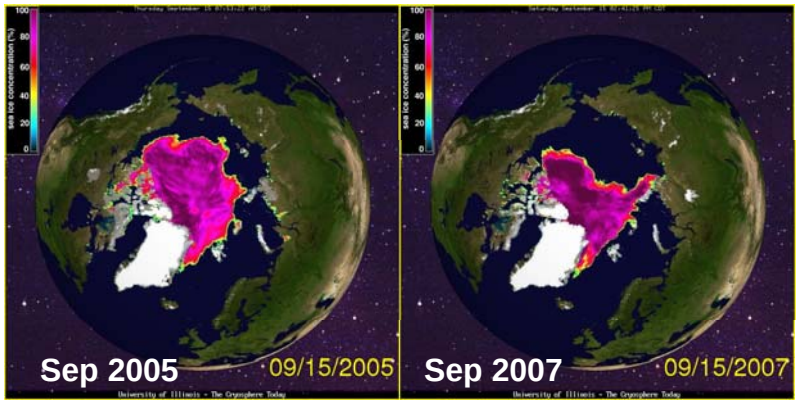
	CCSM(b)			NPS		
	In	Out	Net	In	Out	Net
Fram Strait	2.0/17	-6.9/ -23	-4.9/-6	6.0/45	-8.4/-36	-2.4/+9
Barents Sea Opening	4.8/115.	-0.3/-5	4.5/110	5.0/107	-1.8/-28	3.2/79
FJL-NZ	4.7/32	-0.35/-1	4.35/31	3.4/2.9	-0.8/-0.7	2.6/2.2

'NPS' TRANSPORTS (Maslowski et al., JGR, 2004)

Fram Strait 'in' obs estimates: 7.0 Sv / 50 TW - Courtesy of A. Beszczynska-Möller, AWI

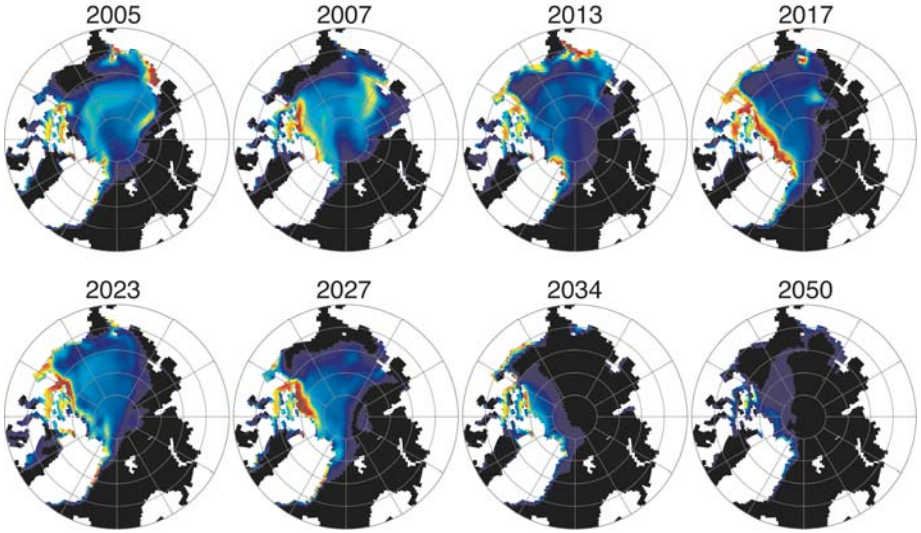
FJL-NZ: near-zero heat transport (Gammelsrod et al., JMS submitted)

Selected model predictions of September sea ice cover/thickness in the Arctic Ocean through 2050



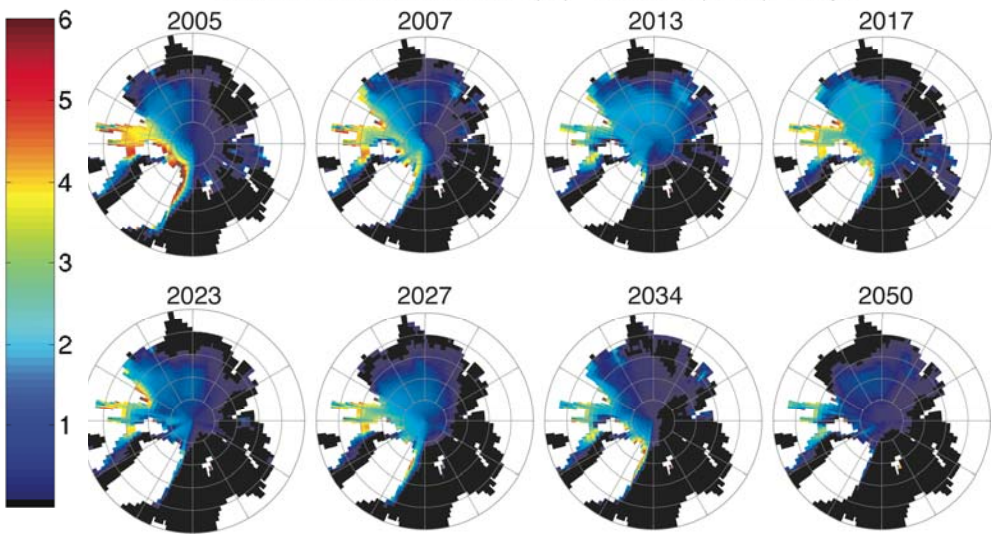
CCSM3

CCSM3 Ice Thickness (m) - ES01(b) - Sep.

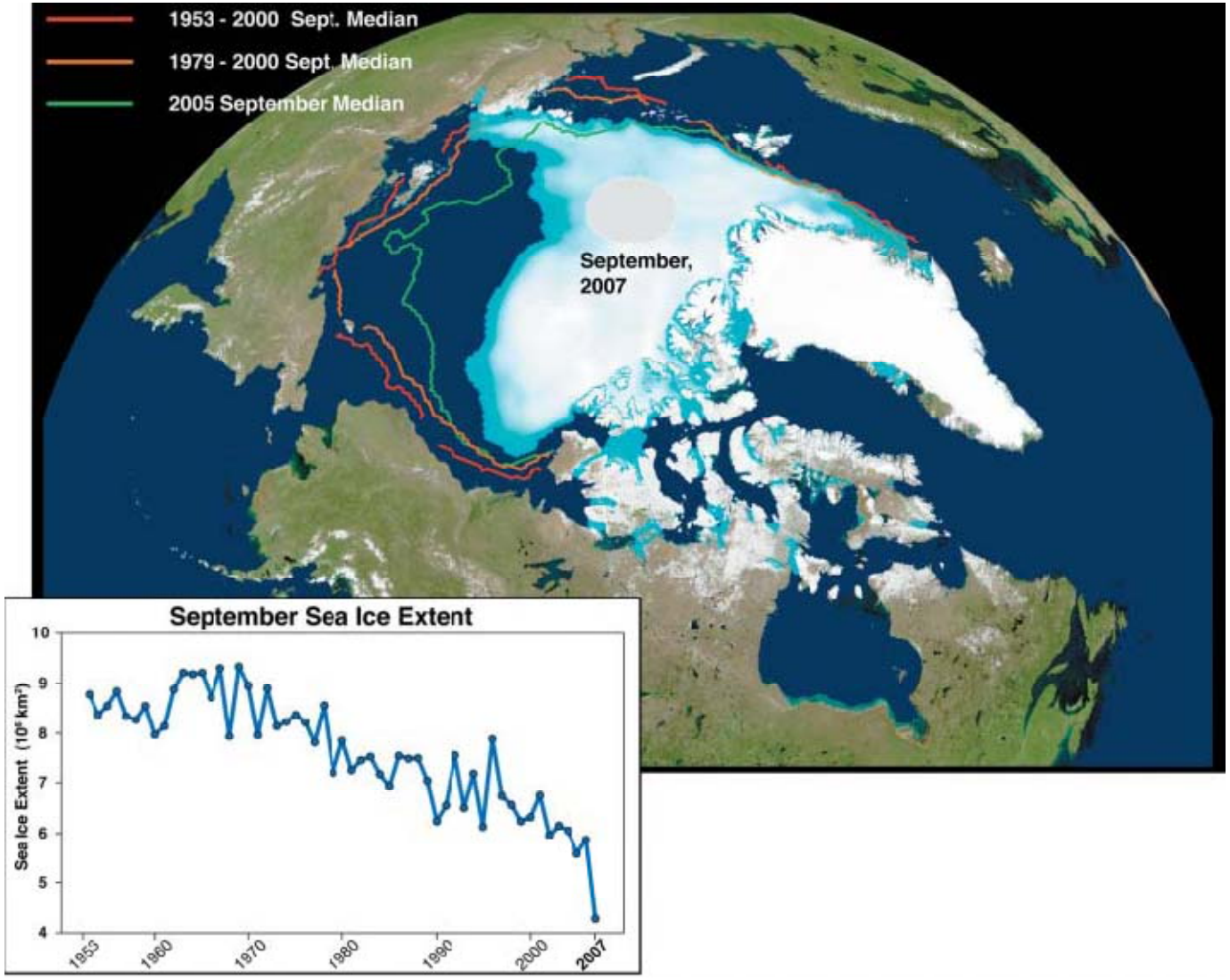


HadGEM1

HadGEM1 Ice Thickness (m) - sresa1b(run1) - Sep.

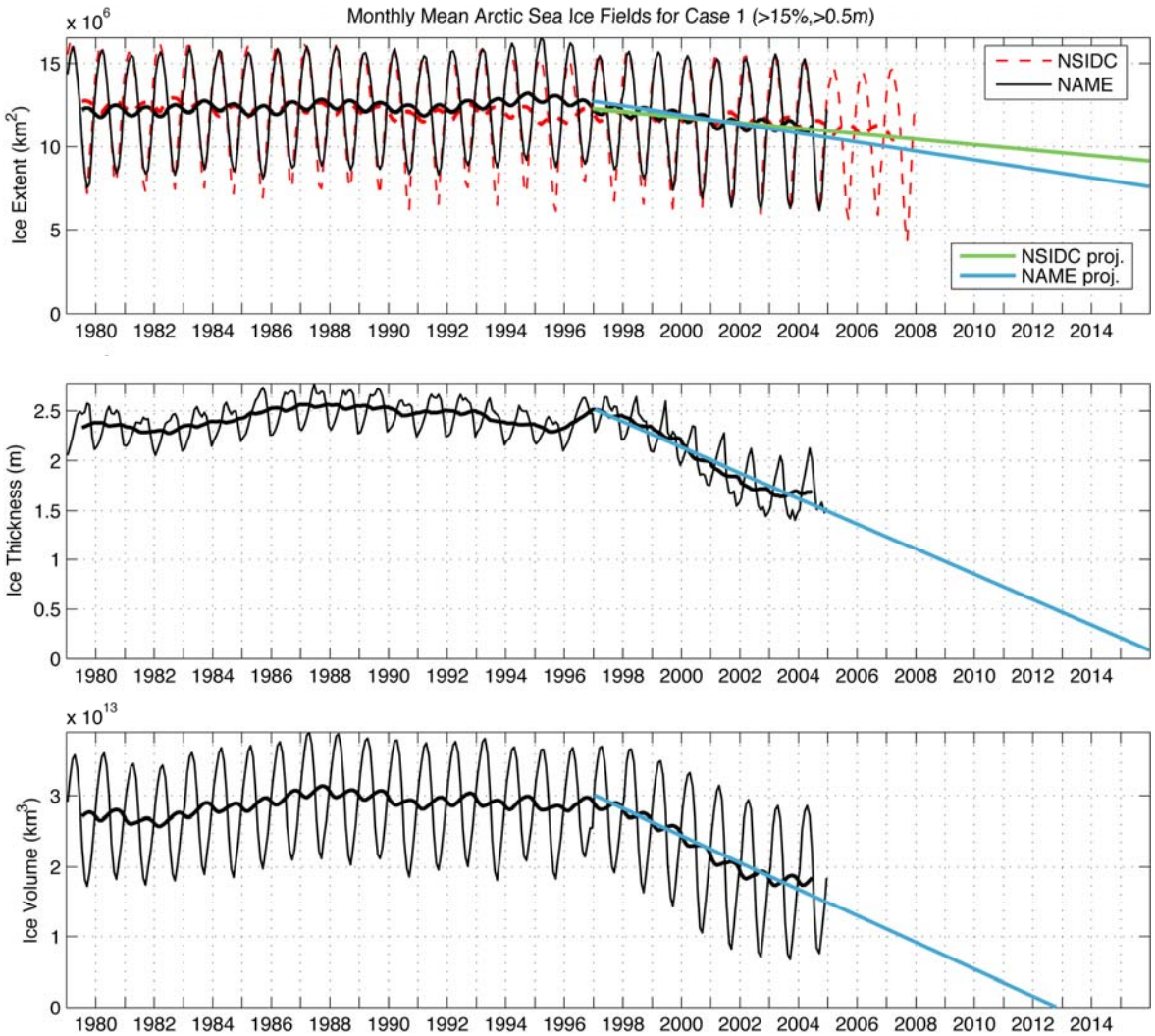


- Too much ice in the western Arctic and over Siberian shelves through 2007
- Too little ice in the eastern Arctic through 2007
- Possibly too thick ice



“Given these conservative model results, along with the remarkable events of 2007, our view is that a seasonally ice-free Arctic Ocean might be realized as early as 2030.”
Stroeve et al., EOS 01/082008

79-04 time series of Ice Extent, Thickness, and Volume



Between 1997-2004:

- annual mean sea ice concentration has decreased by ~17%

- mean ice thickness has decreased by ~0.9 m or ~36%

- ice volume decreased by 40%, which is >2x the rate of ice area decrease

If this trend persists the Arctic Ocean will become ice-free by ~2013!

Conclusions

1. The rate of decrease of sea ice thickness and volume possibly about 2x greater than that of sea ice extent
2. Anomalous export of sea ice through Fram Strait during the mid-1990s a precursor of sea ice decline
3. Oceanic heat advection has contributed significant forcing (>60%) to sea ice melt during the last decade
4. CCSM3/HadGEM1 (and potentially many other GCMs) simulations compared to NPS and observational estimates:
   a) have too weak northward heat fluxes through Bering / Chukchi seas, which explains why they have too much ice in the western Arctic
   b) have too weak northward and recirculating fluxes at Fram Strait, which allow too much ice in the Greenland Sea
   c) simulate too much volume and heat flux through the Barents Sea and try to melt the sea ice cover from the eastern side

   which is why their predictions are too conservative

5. Ice thickness and ocean heat flux data critical for model validation
6. Dedicated computer resources needed to advance Arctic and global climate modeling and prediction

"A linear increase in heat in the Arctic Ocean will result in a non-linear, and accelerating, loss of sea ice."

– Norbert Untersteiner, Professor Emeritus,

University of Washington, July 2006